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Role of the predator, Aphidoletes aphidimyza (Rondani) (Diptera: Cecidomyiidae), in the management of the apple aphid, Aphis pomi DeGeer (Homoptera: Aphididae).

Roger Gilbert Adams
University of Massachusetts Amherst

ROLE OF THE PREDATOR, <u>APHIDOLETES APHIDIMYZA</u> (RONDANI) (DIPTERA: CECIDOMYIIDAE), IN THE MANAGEMENT OF THE APPLE APHID, <u>APHIS POMI</u> DEGEER (HOMOPTERA: APHIDIDAE).

A Dissertation Presented

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Approved as to style and content by:

(Dr. Ronald J. Prokopy), Chairperson of Committee

(Dr. Pedro Barbosa), Member

(Dr. Richard A. Damon, Jr.), Member

James B. Kring

(Dr. James B. Kring), Department Head
Department of Entomology

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ABSTRACT

ROLE OF THE PREDATOR, APHIDOLETES APHIDIMYZA (RONDANI) (DIPTERA: CECIDOMYIIDAE), IN THE MANAGEMENT OF THE APPLE APHID, APHIS POMI DEGEER (HOMOPTERA: APHIDIDAE).

(February 1978)

Roger G. Adams, Jr., B. A., Ottawa University,
M. S., University of Massachusetts, Ph.D., University of Massachusetts

Directed by: Dr. Ronald J. Prokopy

From 1974 through 1976 *Aphidoletes aphidimyza* was by far the most abundant summer predator of the apple aphid, *Aphis pomi*, in a western Massachusetts apple orchard. Population density studies and caging studies showed that the cecidomyiid was responsible for high apple aphid mortality and dramatic population reductions.

Eclosion studies indicated that at least a portion of the *Aphidoletes* population overwintered in the apple orchard; however, adult eclosion did not occur until mid June. Thus, owing to lack of biological synchrony between predator and prey, *A. aphidimyza* was unable to prevent early season aphid damage. Therefore, for season-long management, apple aphid populations need to be maintained below economic threshold levels until the appearance of *A. aphidimyza* in mid June. An economic threshold level of 50 apple aphids per terminal leaf was suggested. Effective season-long apple aphid suppression was achieved through the use of alternate row reduced spray programs.

Oviposition studies showed that *A. aphidimyza* adults will readily oviposit in low density apple aphid colonies. In general, as aphid

density on collected leaves increased, the number of leaves harboring *Aphidoletes* eggs decreased by a factor of approximately 50% at each 100-aphid density interval. However, the mean number of eggs deposited per leaf increased with increasing aphid colony size.

Apple terminal caging studies were conducted to determine the effect of various prey-predator density ratios on apple aphid colony suppression and aphid consumption rates by *Aphidoletes* larvae. In 1976 the overall mean number of apple aphids killed per cecidomyiid was 27.9, ranging from 4.2 to 65.1, depending on prey and predator densities. In 1977 the overall mean aphid consumption rate per cecidomyiid was 18.2, ranging from 13.3 to 24.8. In general, aphid consumption rates per cecidomyiid increased as the number of aphids available per cecidomyiid increased; aphid consumption rates per cecidomyiid decreased with intraspecific competition among *Aphidoletes* larvae for prey. However, a higher degree of aphid colony suppression resulted in cages with a multiple number of cecidomyiids as compared to cages with only 1 cecidomyiid and proportionate aphid densities. Greater aphid colony suppression at multiple number cecidomyiid densities was apparently due to a rapid and thorough predatory influence or coverage over the food zone. In addition, dispersal of *Aphidoletes* larvae to adjacent aphid-harboring leaves occurred earlier and with greater frequency on terminals caged with a multiple number of cecidomyiids as compared to cages with only 1 cecidomyiid present. The ratios up to and including 15 aphids per cecidomyiid were most effective in aphid colony suppression. The *Aphidoletes* oviposition sampling study showed a field ratio of 10.9 apple aphids per cecidomyiid per leaf, which would fall within the ratio range found in caging studies to be most effective in aphid colony suppression.

Laboratory toxicity studies conducted on *A. aphidimyza* eggs and larvae showed that treatments of Guthion, Systox, Sevin, and Phosphamidon have very detrimental effects on *Aphidoletes* populations collected from an unsprayed section of an apple orchard in Belchertown, MA. However, Guthion treatments were of low mortality to *Aphidoletes* eggs collected from a commercial apple orchard in Fitchburg, MA. Thus, differential Guthion resistance appears to exist in *A. aphidimyza* populations collected from 2 areas of the state. Zolone was the only insecticide tested that was of low toxicity to *Aphidoletes* eggs and larvae. However, Zolone is highly toxic to predaceous mites. Thiodan and Imidan were only moderately toxic to *A. aphidimyza*, and are of low toxicity to predaceous mites. All miticides, fungicides, and herbacides tested were of low toxicity to *A. aphidimyza* eggs and larvae.

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INTRODUCTION

The apple aphid, *Aphis pomi* DeGeer, is commonly found in dense colonies on apple throughout the growing season. Serious losses may result in commercial orchards if populations are not suppressed (Madsen *et al*. 1961; Oatman and Legner 1961). Currently, several sprays are required in western Massachusetts apple orchards to assure successful control. Apple aphid injury may be caused in the following ways: (1) feeding on fruits; (2) excretion of honeydew and the subsequent growth of sooty mold fungus on fruits and foliage; (3) leaf curling; (4) stunting of terminal growth; and (5) possible transmission of the organism causing fire blight, *Erwinia amylovora*, (Oatman and Legner 1961; Cutright 1963; Plurad *et al*. 1965). Honeydew additionally serves as a primary food source of the adult apple maggot, *Rhagoletis pomonella* (Walsh), (Boush *et al*. 1969).

We are becoming increasingly aware of the consequences and dangers of total reliance on pesticides to resolve pest problems. Our greatest concerns are: (1) the substantial cost of spray materials, equipment, fuel, and labor; (2) the hazard of pesticide residues in the environment and on market produce; (3) the speed with which pests develop resistance to pesticides; and (4) the reduction of natural enemy populations, thus allowing pests greater freedom to increase in numbers.

Pest outbreaks have often been associated with natural enemy mortality attributed to the disruptive effects of pesticides on the balance between pest and natural enemy populations (Ripper 1956). Increased knowledge of such phenomena led to the development of the concept of pest management, which involves the maximum use of natural enemies of pests supplemented with selective pesticides and other control techniques when necessary. Croft and Brown (1975), in a recent review on the responses of arthropod natural enemies to insecticides, state that, "the initial step in developing an integrated pest control program is to assess the pesticides applied against pest arthropods for their effect on the natural enemies." The same authors state that almost all the pesticides commonly applied to fruit crops have been tested for toxicity to important mite predators, and that numerous chemicals have been found to be negligibly toxic.

Moore (1976) reported alternate row spray programs to be successful in controlling apple aphids and in allowing aphid natural enemy survival. In addition, such programs result in reductions in costs and pesticide usage.

During initial studies on the natural enemy complex of _A. pomi_ in a western Massachusetts apple orchard, I found an aphidophagous cecidomyiid, _Aphidoletes aphidimyza_ (Rondani), to be an abundant summer predator decimating colonies of the apple aphid. The main objective of this study was to determine the effectiveness and ascertain the limitations of _A. aphidimyza_ in reducing and managing orchard populations of the apple aphid.

LITERATURE REVIEW

Apple Aphid, *Aphis pomi* DeGeer

The apple aphid was first recorded as a serious pest on apple trees in eastern United States in 1849 (Matheson 1919). Since then, numerous studies have been conducted on various aspects of apple aphid biology and ecology (Baker and Turner 1916; Matheson 1919; Cutright 1930; Oatman and Legner 1961; Westigard and Madsen 1964; 1965; Specht 1972).

The apple aphid overwinters in the egg stage primarily on the distal 10 inches of apple terminal growth. Hatching occurs in early spring, and stem mothers mature in approximately 2 weeks. Reproduction continues for about 1 month and each female produces an average of 50 living young. During subsequent generations, numerous winged forms (alatae) are produced. Some of the alatae migrate to alternate summer hosts, but the majority fly to other apple trees. Dense colonies form on tender, succulent foliage of vigorous growing terminals (Baker and Turner 1916; Matheson 1919; Patch 1923; Cutright 1930, 1963).

As the growing season progresses the apple aphid population is adversely affected. The following factors have been shown or suggested to contribute to population declines: apple variety, growth patterns of host, weather, emigration of alatae, and natural enemies (Cutright 1930; Leroux 1959; Oatman and Legner 1961; Westigard and Madsen 1965).

The apple aphid can be controlled with insecticides, but reinfestation is rapid (Pielou and Williams 1961a,b). Also, sprays for aphids have been shown to have a detrimental effect on natural enemies of mites and other pests (Croft and Brown 1975).

Madsen *et al*. (1975) were able to eliminate routine sprays and reduce the number of sprays needed to obtain aphid control in British Columbia apple orchards. In 1973, 2 of 6 orchards each received 1 spray treatment for apple aphid control. The following year no sprays were applied specifically for apple aphid control. In each year, damage in all 6 orchards was nil. The authors note, however, that the apple aphid is rarely a problem on mature trees on standard rootstocks in British Columbia. The need for treatment was established by sampling aphid populations. Sprays were recommended when 50% of the leaves sampled were aphid infested.

A number of workers have studied or reported the occurrence of natural enemies of _A. pomi_. Cutright (1963) stated that the apple aphid is heavily attacked by coccinellids, syrphids, lacewings, and various parasites. Westigard and Madsen (1965) found anthocorids, coccinellids, and lacewings to predominate, while parasitism was less than 1%. Oatman and Legner (1961) noted that coccinellids were the most abundant adult predators, while syrphid fly larvae were the most numerous immatures feeding on apple aphids. Anthocorids and lacewings were observed much less frequently; parasitism was less than 0.1%. Bonnemaison (1972) found anthocorids, coccinellids, lacewings, syrphids, cecidomyiids (_Cecidomya_[1] sp.), and parasitic Hymenoptera to be the main natural enemies of the apple aphid in France. Holdsworth (1970) reported _Aphidoletes cucumeris_ (Lintner)[2], chamaemyiids, anthocorids, and syrphids to be most common in an Ohio apple orchard. In Nova Scotia,

[1]Synonym for _Aphidoletes_.

[2]Synonym for _Aphidoletes aphidimyza_ (Rondani).

Evenhuis (1961) observed syrphids, cecidomyiids (Phaenobremis[3] sp.) and chamaemyiids to be the primary Dipterous enemies of the apple aphid.

Aphidoletes aphidimyza (Rondani)

Studies of the aphidophagous cecidomyiids have been hampered by the small size and taxonomic confusion of these insects. Recent studies have helped reduce the taxonomic uncertainty (Gagne 1971, 1973; Harris 1973). Harris (1973) reported 33 synonym names for Aphidoletes aphidimyza and stated that there are 5 good species of aphidophagous cecidomyiids described in the literature. A. aphidimyza, though behaviorly similar to A. urticariae (Kieffer), is far more abundant and has a much greater host range than the latter species. Both A. abietis (Kieffer) and A. thompsoni Mohn have been reported to feed only on adelgids. Monobremia subterranea (Kieffer) is a rare species reported to feed only on certain root aphids (Harris 1973). However, Gagne (1971) found only 3 valid species of Aphidoletes described from North America: A. aphidimyza, A. urticariae, and A. thompsoni.

Larvae of A. aphidimyza are small (2mm in length) bright orange colored maggots that feed on many species of aphids (Nijveldt 1954; Harris 1973). Wilbert (1973, 1974) reported that larvae locate prey over a short distance by odor; however, searching behavior was slight when food was lacking. During feeding, larvae paralyse aphids by injecting salivary toxins. Since there is no struggle by the aphid, shrivelled bodies of aphids are generally found with their mouthparts still anchored in plant tissue (Mayr 1975). Larval development is

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[3] Synonym for Aphidoletes.

usually completed in 7 to 14 days depending on temperature (Davis 1916; Azab, *et al.* 1965).

The number of aphids killed by each larva during its development vary greatly. Uygun (1971) reported a minimum requirement of 7 *Myzus persicae* (Sulzer), while Nijveldt (1966) found an average diet to range from 5.2 large green peach aphids to 14.7 small aphids per larva. George (1957) observed 40 to 60 *Brevicoryne brassicae* (L.) killed per larva. Roberti (1946), working with *Aphis gossypii* Glover, reported 60 to 80 aphids killed per larva. Dunn (1949) noted that many more aphids may be killed than are actually needed to meet nutritional requirements of the predator.

Pupation usually occurs in the soil and is completed in 1 to 2 weeks. The species overwinters in the soil as a larva within a cocoon and pupation occurs during the spring. Adults are nocturnal and live for about 1 week. Each female lays approximately 100 small, orange, oval eggs in or near an aphid colony. Eggs hatch in about 3 days. Under favorable conditions at temperatures of 21°C., the complete life cycle from egg to adult takes approximately 3 weeks (Davis 1916; Azab *et al.* 1965; Nijveldt 1966; Uygun 1971; Harris 1973).

Adult females are quite proficient at locating aphid colonies. El Titi (1974b) reported that, during 1 night, *Aphidoletes* adults released in a greenhouse succeeded in finding and laying a great number of eggs on a single aphid-infested plant among 75 aphid-free plants. A number of factors have been shown to elicit *Aphidoletes* oviposition: certain components of honeydew (mainly arginine, tyrosine, and fructose), cornicle secretions, and dead aphids. The effect of living aphids is non-specific (El Titi 1973, 1974a).

Pollard (1969) assessed the role of Aphidoletes sp. as a predator of B. brassicae on brussel sprouts using the predator removal technique, and reported that cecidomyiid larvae quickly eliminated aphid colonies. Mayr (1973) reported that biological control of aphids in the greenhouse is possible with A. aphidimyza, but requires continuous colonization of the midges since artificial diets are not available. El Titi (1974b) found that cecidomyiid larvae reduced M. persicae numbers on Brassicas in a greenhouse to a very low level in 2 to 7 weeks, depending on the number of female midges released.

Though some reports of A. aphidimyza feeding on A. pomi do appear in the literature, quantitive studies are lacking (Evenhuis 1961; Holdsworth 1970; Bonnemaison 1972) (see Literature Review section on A. pomi).

MATERIALS AND METHODS

Experimental Series A

Population densities. Population densities of the apple aphid and its natural enemies were recorded from 1974 through 1976 in an apple orchard at the Fruit Research Center in Belchertown, MA. Individual trees to be studied were designated randomly and labeled for identification. To sample, the 3 most distal leaves measuring 1 inch or more in length on young terminals were collected. Foliage on young terminals is easily recognized by its light green color, in contrast to the dark green coloration of older foliage. In 1974, 1 young terminal from 8 trees was sampled on 8 dates, while in 1975 and 1976 foliage was sampled from 1 terminal on 24 trees on 12 and 10 dates, respectively. The samples were placed in separate half-pint ice cream containers and stored on ice during transit to the laboratory for examination. A mite brushing machine was used to remove specimens from foliage onto oiled glass plates. Counts were made with the aid of a microscope and a counting grid. Aphid mortality due to *Aphidoletes aphidimyza* activity was recorded by counting the number of sucked aphids present on sampled foliage. Mayr (1975) reported that during feeding, *Aphidoletes* larvae paralyse aphids by injecting salivary toxins. Since there is no struggle by the prey, shrivelled bodies of sucked aphids are generally found with their mouthparts still anchored in plant tissue. Aphids attacked by larger and more forceful predators such as coccinellids, syrphid fly larvae, or lacewing larvae are often dislodged from the foliage. In contrast to aphids killed by *Aphidoletes* larvae, which remove prey body fluids, aphids recently killed by pesticide treatments retain their body fluids, and thus do not acquire a collapsed or shrivelled body until dehydration occurs several days after death. The short intervals between sampling dates aided in the detection of aphid mortality due to pesticide treatments. With the exception of an accidental insecticide application in mid August of 1974, the study area utilized for Series A experiment did not receive insecticide treatments. To avoid possible confusion of mortality factors, recording of sucked aphids was discontinued subsequent to the accidental treatment.

Aphidoletes oviposition. To study the size of apple aphid colonies preferred by Aphidoletes for oviposition, 95 leaves harboring apple aphids and Aphidoletes eggs were collected for examination. No dead aphids or cecidomyiid larvae were present on these leaves. The aphids and eggs were removed and counted using methods described above.

Aphidoletes overwintering site and time of eclosion. In the spring of 1976 eclosion cage studies were conducted to determine: (1) whether Aphidoletes populations overwinter in the apple orchard, and if so, (2) the time of the year when adult eclosion occurs. Ten eclosion cages were placed over the soil beneath apple terminals which had harbored Aphidoletes larvae the previous fall. The tent-like cages were constructed from 3, 2½ foot wooden poles laced together at the top with string. The cages were secured in place by driving the frame ca. 4 in. into the soil. To enclose the cages, white sheer nylon fabric was stapled to the frame. Each cage was fitted with an 18 in. nylon zipper for easy access to the interior. Within each cage, a yellow cardboard sticky trap, secured on a short stick driven into the ground, was used to capture Aphidoletes adults which emerged. Previous experience had shown that Aphidoletes adults are captured by these traps.

Density ratios of Aphis pomi to Aphidoletes aphidimyza. During 1976 and 1977 apple terminal caging studies were conducted to assess the feeding behavior of Aphidoletes larvae and apple aphid colony suppression at various prey-predator density ratios.

Terminal cages were constructed from clear, 1 quart polyvinyl-chloride (PVC) cylindrical containers 4½ in. in diam. To make a cage, the ends of 2 containers were removed and the containers glued together. Glue was made by dissolving PVC scraps in chloroform. One end of each cage was covered with sheer nylon fabric, while an orthopedic stockinet sleeve closed the other end. Cages were painted white to moderate inside temperatures. Cages were placed over terminals and the sleeves tied closed with string. Spacial orientation of caged terminals was maintained by use of leader strings from the cage to adjacent branches.

In 1976 terminals were caged with the following starting ratios of apple aphids to Aphidoletes eggs: 20 to 0, 20 to 1, 20 to 4, 20 to 8, 60 to 0, 60 to 1, 60 to 4, 60 to 16, 180 to 0, 180 to 1, 180 to 4, and 180 to 16. Each ratio was replicated 3 times. The following ratios were utilized in 1977: 12 to 1, 36 to 3, 15 to 1, 45 to 3, 18 to 1, and 54 to 3. Four replicates and 1 control were used for each starting ratio. Controls consisted of starting ratio aphid densities caged without cecidomyiids. Starting ratios were established on a single leaf (the primary leaf) of naturally infested apple terminals. Excess specimens were removed from the primary leaf until the desired aphid to cecidomyiid ratio was achieved. Aphid removals were made in proportion to the age structure and spacial distribution of the aphid colony on the primary leaf, with the intent of similar representation of aphid morphs among caged colonies. Insects were removed from all secondary leaves on the terminal to be caged. No *Aphidoletes* larvae or dead aphids were present at the start of the experiment. Starting ratios in each cage were maintained until at least 1 cecidomyiid egg had hatched. Eggs failing to hatch within 3 days were replaced by young larvae. Data were recorded throughout the cecidomyiid larval developmental period, and consisted of the number of living aphids, sucked aphids, and *Aphidoletes* larvae present on the primary and secondary leaves. Any sucked aphids found were removed. Insects on the inside surfaces of the cage itself were also recorded and removed.

Experimental Series B

Reduced spray versus full spray application. During 1974 and 1975 alternate row reduced spray pesticide applications were evaluated for control of the apple aphid and for their effects on predator populations. Tests were conducted at the Fruit Research Center in Belchertown, MA. An experimental apple orchard was divided into 3 treatment blocks: full spray (sprayer passes down all rows spraying 2 sides of tree), reduced spray (sprayer passes down alternate rows spraying only 1 side of tree), and unsprayed control. Each block consisted of 8, 5-tree rows of mature apple trees of 4 varieties: MacIntosh (3 rows), Red Delicious (3), Cortland (1), and Puritan (1). A standard pesticide spray program for commercial apple orchards in Massachusetts was employed utilizing the above mentioned treatments. Treatments were applied by orchard speed-sprayer (Hardie-Lockwood) at recommended dosages. Schedule and rates of application used in 1974 and 1975 are presented in Tables 5 and

6, respectively.

Foliage sampling methods were the same as those described in the Population Densities section of Experimental Series A. In 1974, 1 young terminal from 8 trees per treatment was sampled on 8 dates. Damage was estimated visually and rated as extensive, noticeable, or not noticeable, based on the presence of leaf curling and honeydew accumulation. In 1975, foliage from 1 terminal on 24 trees per treatment was sampled on 12 dates. Data were analysed statistically by Least-squares analysis of variance and Duncan's multiple range test for significant differences between treatments.

Toxicity of orchard pesticides to Aphidoletes. To determine the susceptibility, resistance, or tolerance of A. aphidimyza to orchard pesticides, toxicity studies were conducted on eggs and larvae. Pesticides and formulations tested were as follows: Imidan WP 50%, Zolone EC 3 lbs/gal, Plictran WP 50%, Omite WP 30%, Thiodan WP 50%, Systox EC 6 lbs/gal, Guthion WP 50%, Thiram WP 50%, Captan WP 50%, Sevin WP 50%, Phosphamidon EC 8 lbs/gal, and Glyphosate EC 4 lbs/gal.

A. aphidimyza eggs collected from the Belchertown orchard were tested using the slide dip method (Anonymous 1968), with certain modifications. To determine ovicidal activity, it was necessary to differentiate between surviving and moribund larvae and nonhatching eggs. To accomplish this, eggs were placed on double-stick Scotch^{R} brand adhesive binding tape affixed to a microslide and dipped for 5 seconds in chemicals mixed with distilled water at dosages equivalent to those recommended for grower application to apple trees. Each chemical was replicated 5 times with 10 eggs per replicate. Check eggs were dipped in distilled water. All slides were placed on plastic trays and held at ca. 24°C. and 95% relative humidity for the duration of the experiment. The holding chambers were clear plastic shoe boxes (with covers) containing a layer of moist cotton on the bottom to maintain humidity. Egg and early larval mortality were determined at 72 hours after treatment. At that time, eggs which failed to hatch were considered dead, and those larvae that had hatched from treated eggs but had remained on the microslides were considered moribund or dead (Nakashima and Croft 1974). Per cent total mortality was calculated as follows:

$$T = \frac{A + B}{C} \times 100$$

where T is the per cent total mortality, A is the actual number of eggs which failed to hatch, B is the actual number of larvae which remained on microslides 72 hours after treatment, and C is the total number of eggs tested per treatment.

Third and fourth instar Aphidoletes larvae collected from the Belchertown orchard were also tested for susceptibility to orchard pesticides. The orchard block from which larvae were collected had not received insecticide or miticide treatments for 6 years. To test, a small quantity of each pesticide mixed with distilled water at field dosages was placed in a styrofoam cup, and larvae immersed for 10 seconds (Colburn and Asquith 1971). Check larvae were immersed in distilled water. Each pesticide was replicated 5 times with 10 larvae per replicate. Treated specimens were removed from pesticide mixtures by emptying contents of a test cup into a second cup covered with sheer nylon fabric. The fabric holding the treated larvae was then removed and placed on filter paper. Larvae were transferred to clean styrofoam cups with lids and maintained in holding chambers at conditions described above for the slide dip testing method. Lids for test cups were made by cutting additional styrofoam cups in half horizontally and covering the upper half with sheer nylon fabric, which was glued in place with Elmer's Glue-All[R]. Late instar larval mortality was recorded every 24 hours and final per cent late-larval mortality calculated from mortality values after 96 hours. Larvae failing to show movement after prodding with a camel-hair brush were considered to be dead.

Toxicity studies were also conducted on Aphidoletes eggs and late instar larvae collected from an apple orchard at Marshall Farm in Fitchburg, MA. The aim was to determine whether differential resistance to Guthion existed between Fitchburg and Belchertown Aphidoletes populations. The Marshall Farm apple orchard has received 7 to 8 Guthion treatments annually for 7 years at the dosage rate of $\frac{1}{2}$ lb/100 gal. Testing methods and materials used were the same as those described above.

RESULTS

Experimental Series A

Population densities. Over the 3 year period, *A. aphidimyza* was by far the most abundant summer predator of the apple aphid. A total of 1909 individuals (eggs and larvae) were found on sampled foliage. Syrphids (eggs and larvae) were next most abundant with 177 individuals found. Anthocorids (16 individuals), lacewing larvae (6), and coccinellids (1) appeared only occasionally.

In 1974 (Fig. 1) the apple aphid population reached 2 major peaks, occurring approximately 1 month apart. *A. aphidimyza* eggs were first collected from sampled foliage on June 28; larvae first appeared on July 10. With the appearance of the larvae, sucked aphids also became noticeable. In early July the *Aphidoletes* population rose rapidly in response to increasing apple aphid numbers. *Aphidoletes* puparial formation is reflected by the sharp decline in the number of larvae on sampled foliage from July 17 to August 14. As the cecidomyiid larvae left the foliage, a corresponding drop in apple aphid mortality was observed. In early August the apple aphid population, then free from predator pressure, rose to reach its second seasonal peak. In mid August the apple aphid population was unfortunately decimated by an accidental Imidan spray application. To avoid possible confusion of mortality factors, recording of sucked aphids was discontinued subsequent to the accidental treatment. However, the second generation of *Aphidoletes* had appeared and begun to respond numerically to the high aphid population.

The data in 1975 (Fig. 2) show an even closer correlation between the apple aphid and _A. aphidimyza_, as indicated by the close similarity of the population curves and frequency of low amplitude population oscillations. There was again a strong correlation between the abundance of _Aphidoletes_ larvae on sampled foliage and the degree of apple aphid mortality. Apple aphid populations rose at each point in the growing season where the number of _Aphidoletes_ larvae and the corresponding aphid mortality values were at their lowest levels (June 22, July 20, August 17, and 31).

The populations data from 1976 (Fig. 3), though not as clear-cut as in 1975, indicate trends similar to previous years. A very large apple aphid population declined rapidly upon the appearance of _A. aphidimyza_ in mid June.

Together these data strongly suggest that _A. aphidimyza_ is an important mortality factor. Despite its suppressing and regulating effects, _A. aphidimyza_ was not, however, successful in preventing early season damage due to aphid activities. Leaf curling and honeydew accumulation was extensive, having reached high levels prior to the appearance of _A. aphidimyza_ in the orchard.

Aphidoletes overwintering site and time of eclosion. _A. aphidimyza_ was found to overwinter in the Belchertown orchard. On June 11, 1976, 4 adults of _A. aphidimyza_ were captured on yellow sticky traps within eclosion cages placed in the orchard.

Aphidoletes oviposition. Results of the study on size of aphid colonies preferred by _A. aphidimyza_ for oviposition are presented in Table 1. The data show that of the 95 leaves collected harboring _Aphidoletes_ eggs, 47 had aphid colony densities ranging from 1 to 100 individuals. Of these 47 leaves, 19 had aphid colony densities of 25 individuals or less. Twenty-five of the 95 leaves had aphid densities in the 101 to 200 range. In general, as aphid density on collected leaves increased, the number of leaves with Aphidoletes eggs decreased by a factor of approximately 50% at each aphid density interval. However, the mean number of eggs deposited per leaf increased with increasing apple aphid colony size. Overall, experimental means of 133.6 apple aphids and 12.3 Aphidoletes eggs were recorded per collected leaf. These means reduce to a field ratio of 10.9 aphids per cecidomyiid per leaf.

Density ratios of Aphis pomi to Aphidoletes aphidimyza - 1976. Results of the 1976 caging studies on the feeding activities of A. aphidimyza larvae and apple aphid colony suppression at various aphid to cecidomyiid density ratios are presented in Table 2. To visualize trends in the results, starting ratios were reduced to a single cecidomyiid basis. For example, a starting ratio of 60 apple aphids to 4 Aphidoletes eggs reduced to a ratio of 15 to 1. The experiment showed that Aphidoletes accounts for considerable apple aphid mortality, thus confirming the suggestion of the field sampling population density studies. In every case, those aphid colonies caged with Aphidoletes were either reduced in size or decimated within 12 days. Control aphid colonies (without Aphidoletes) at densities of 20 and 60 individuals per primary leaf expanded considerably in size, while control colonies of 180 aphids per primary leaf decreased. This decrease was due primarily to emigration within apple aphid colonies through the production of alate forms. Caging studies in 1976 were conducted in early August when apple foliage is generally less favorable for the development of large aphid colonies as compared to periods earlier in the growing season when foliage is younger and more actively growing. As a result, the production of aphid alates in late summer may occur at aphid density levels much lower than those that would stimulate aphid wing production in early or mid summer. Caging studies in 1977 were conducted in early July. As a result, caged apple aphid colonies were able to reach much higher density levels than control colonies in 1976.

The reduced ratios effective for apple aphid colony decimation were those up to and including 15 to 1 (Table 2). At each of these ratios, the mean number of living aphids per cage at the end of the experiment was less than 1. Starting ratios of the most effective reduced ratios all included multiple numbers of Aphidoletes eggs (20 to 8, 60 to 16, 20 to 4, 180 to 16, and 60 to 4). However, aphid consumption rates per cecidomyiid were lowest (4.2 to 19.9 aphids killed) for those ratios which were most effective in aphid colony suppression.

In no case was a starting ratio with only 1 cecidomyiid (20 to 1, 60 to 1, and 180 to 1) successful in decimating a caged apple aphid colony. The starting ratio of 180 to 4 (reduced to 45 to 1) was also ineffective in aphid colony decimation. However, the highest aphid consumption rates (32.3 to 65.1 aphids killed) per cecidomyiid occurred at the ratios least effective in aphid colony suppression.

Aphid consumption rates per cecidomyiid were influenced by the number of aphids available; as the reduced ratio values increased, the number of aphids killed per cecidomyiid increased. The overall experimental mean number of aphids killed per cecidomyiid was 27.9, ranging from 4.2 to 65.1.

<u>Density ratios of *Aphis pomi* to *Aphidoletes aphidimyza* - 1977.</u> Results of the 1977 apple terminal caging studies are presented in Table 3. For each reduced ratio, the mean number of aphids killed per cecidomyiid was consistently highest (18.3, 20.0, and 24.8) for those starting ratios with only 1 cecidomyiid present (12 to 1, 15 to 1, and 18 to 1). Lowest aphid consumption rates per cecidomyiid (13.3, 15.5, and 17.5) were for those starting ratios with 3 cecidomyiids present (36 to 3, 45 to 3, and 54 to 3). The overall experimental mean number of apple aphids killed per cecidomyiid was 18.2, ranging from 13.3 to 24.8.

The degree of apple aphid colony suppression achieved at the various prey-predator density ratios is indicated by the % change in number of aphids present at the beginning compared with the end of the experiment. Per cent change in aphid numbers was calculated by the formula:

$$C = - \frac{(S - A)}{(S)} \times 100$$

where C is the % change in number of aphids present at the beginning compared with the end of the experiment, S is the number of aphids present at the start of the experiment, and A is the number of living aphids present at the end of the experiment. When reduced ratios were compared, the greatest reductions in aphid numbers (86%, 59%, and 50%) occurred for those starting ratios having 3 cecidomyiids present (36 to 3, 45 to 3, and 54 to 3), while the lowest reductions and/or increases in aphid numbers (-27%, -45%, and +56%) occurred for single cecidomyiid starting ratios (12 to 1, 15 to 1, and 18 to 1). Aphid increases in control colonies (without *Aphidoletes*) ranged from 482 to 1186%. The starting ratio of 36 to 3 was the most effective for aphid colony suppression (86% reduction in aphid numbers), even though it had the lowest aphid consumption rate (13.3) per cecidomyiid. In contrast, the starting ratio of 18 to 1 had the highest aphid consumption rate (24.8) per cecidomyiid, but showed the poorest aphid colony suppression (56% increase in aphid numbers).

In addition to the effect of predator density, or intraspecific competition for prey, the number of aphids available per cecidomyiid was again, as in 1976, shown to be important in determining aphid consumption rates by A. aphidimyza. Increasing numbers of aphids in starting ratios with only 1 cecidomyiid (12 to 1, 15 to 1, and 18 to 1) resulted in increasing mean numbers of aphids killed per cecidomyiid (18.3, 20.0, and 24.8). Likewise, increasing numbers of aphids in starting ratios with 3 cecidomyiids (36 to 3, 45 to 3, and 54 to 3), resulted in increasing aphid consumption rates per cecidomyiid (13.3, 15.5, and 17.5).

Dispersal by Aphidoletes larvae. Apple aphids were found to disperse to secondary leaves irrespective of the presence of Aphidoletes larvae on the primary leaf of caged terminals. In addition, 4 to 5 day old Aphidoletes larvae were found capable of considerable movement within the food zone. For example, the data in Table 4 show the extent of larval movement that occurred over a 12 day period on an apple terminal caged with a starting ratio of 60 to 16. Over time, aphid numbers on the primary leaf fell to zero through the combination of Aphidoletes predation and apple aphid dispersal to secondary leaves. As aphid numbers on the primary leaf became depleted, Aphidoletes larvae vacated the primary leaf and moved to secondary leaves. There, Aphidoletes larvae found a new supply of aphids, the result being complete apple aphid mortality on the caged terminal by the end of the experiment.

Experimental Series B

Reduced spray versus full spray application. In 1974 no significant differences in apple aphid numbers were found among treatments on each sampling date (Table 7). Lack of significant differences, despite large numerical differences, was due to high variability owing to low sample numbers.

The apple aphid population reached its highest seasonal peak in the unsprayed control block on July 17, averaging 518.75 aphids per terminal. On August 14, peaks of 478.88 and 140.63 aphids per terminal were reached in the reduced and full spray treated blocks, respectively. Apple aphid populations were highest throughout the growing season in the unsprayed control block with the exception of the period from July 30 to August 14, when aphid numbers were greatest on reduced spray treated trees. With the exception of August 21, apple aphid numbers were lowest in the full spray treated block. Aphid damage in reduced and full spray treated blocks was not noticeable, but was extensive in the unsprayed control block. See the Discussion section of Experimental Series A for a discussion of economic threshold levels of the apple aphid.

A. aphidimyza populations (eggs and larvae) also reached their highest peak in the unsprayed control block on July 17, averaging 70.4 cecidomyiids per terminal. A high peak of 7.63 cecidomyiids per terminal was found on July 30 in the reduced spray treated block, while a peak of 8.88 cecidomyiids per terminal appeared on full spray treated trees on August 21. From July 25 to 30, significantly more cecidomyiids were found on reduced versus full spray treated trees. In addition, significantly more cecidomyiids were found from July 30 to August 14 on reduced spray treated trees as compared to those of the unsprayed control. Only on August 21 were there significantly more cecidomyiids on full versus reduced spray treated trees.

In general, the 1974 data show that Aphidoletes appeared later and was less abundant in orchard blocks as pesticide treatments increased in coverage from unsprayed control to reduced spray to full spray treatments. However, it is interesting to note that, with the exception of August 21, Aphidoletes was always most abundant in the treatment block where apple aphids were most abundant. In addition, A. aphidimyza was the only apple aphid predator found in noticeable numbers on insecticide treated foliage. Totals of 3 syrphid fly eggs and 1 syrphid larva were found on treated foliage, while 30 syrphids (eggs and larvae) were found on sampled foliage in the unsprayed control block.

In 1975 there were again no significant differences in apple aphid numbers in reduced versus full spray treated blocks (Table 7). With the exception of August 31, apple aphids were always more numerous (though not always statistically so) on sampled foliage of the unsprayed control as compared to reduced spray treated foliage.

The apple aphid population in the unsprayed control block reached major peaks of 212.83 and 143.21 aphids per terminal on July 6 and 27, respectively. On August 17 a peak of 31.88 aphids per terminal was reached in the reduced spray treated block, while a peak of 13.21 aphids per terminal was reached in the full spray treated block on August 31. Aphid damage in reduced and full spray treated blocks was not noticeable, but was extensive in the unsprayed control block.

From June 29 through August 24, significantly more cecidomyiids were found on foliage in the unsprayed control block as compared to foliage in treated blocks. Only on September 7 were there significantly more cecidomyiids on reduced spray treated foliage as compared to foliage of the unsprayed control. However, when compared with the full spray treatment, significantly more cecidomyiids were found on reduced spray treated foliage on August 10 and September 7. In contrast, on July 20, significantly more cecidomyiids were found on full spray treated foliage than on foliage receiving reduced spray treatments. As in the previous year, Aphidoletes appeared earlier and was more abundant in the unsprayed control block than in treated blocks. However, in contrast to the previous year, Aphidoletes numbers in the reduced and full spray treated blocks were very similar. In addition, Aphidoletes appeared earlier in the full spray treated block than in the block which received reduced spray treatments. This may have been due to greater aphid survival during this period on watersprouts and suckers on interior portions of full spray treated trees.

As in 1974, Aphidoletes numbers on individual sampling dates were highest (with the exception of July 27 and August 31) in the treatment block where apple aphids were most abundant. In 1975 not a single syrphid fly egg or larva was found on sampled treated foliage, while 105 syrphids (eggs and larvae) were found on sampled foliage from the unsprayed control block.

Toxicity of orchard pesticides to Aphidoletes eggs. Results of toxicity studies conducted on eggs of A. aphidimyza are presented in

Table 8. Per cent egg mortality (EM) was generally low, with the exception of the Guthion (Belchertown population) and Sevin treatments, where 86% and 72% of the eggs, respectively, failed to hatch. Phosphamidon was moderately toxic (34%) to Aphidoletes eggs. Treatments of the miticides Plictran and Omite, the fungicides Thiram and Captan, and the insecticides Zolone, Thiodan, Imidan, and Systox were all of low toxicity (4 to 14%) to A. aphidimyza eggs at the dosages tested. In contrast to the high toxicity of Guthion to Aphidoletes eggs collected from Belchertown, mortality of eggs collected from an apple orchard at Marshall Farm in Fitchburg, MA. and treated with Guthion was very low (6%). Egg mortality for the Belchertown and Fitchburg checks was 4% and 5%, respectively.

However, a few materials that were of low toxicity to Aphidoletes eggs were moderately or highly toxic to first instar larvae hatching from treated eggs. Such early larval mortality (ELM) was highest (57%) for Aphidoletes larvae hatching from Systox treated eggs, while Imidan and Thiodan treatments were of moderate toxicity (24 to 29%) to young larvae. Treatments of Sevin and Phosphamidon, in addition to being highly or moderately toxic to Aphidoletes eggs, were also moderately toxic (21 to 27%) to larvae hatching from treated eggs. Early larval mortality was low for Omite, Captan, and Guthion (Belchertown) (2 to 14%). The value of 14% ELM for the Guthion (Belchertown) treatment may be somewhat less than representative due to the low number of hatching Aphidoletes eggs (7 out of 50) in the Guthion treatments. Toxicity of Guthion treatments to Aphidoletes larvae hatching from eggs collected in Fitchburg was moderate (38%). No ELM was found in the following treatments: Zolone, Thiram, and Plictran. ELM was 6% in the Belchertown check, while no ELM occurred in the Fitchburg check.

Per cent total mortality (TM) was high for treatments of Guthion (Belchertown) (88%), Sevin (78%), Systox (60%), and Phosphamidon (52%). Per cent TM was moderate for Imidan (30%), Thiodan (34%), and Guthion (Fitchburg) (42%), and was low for the following treatments: Zolone (4%), Thiram (6%), Omite (8%), Captan (10%), and Plictran (14%). Per cent TM for the Belchertown and Fitchburg checks was 10% and 5%, respectively.

Toxicity of orchard pesticides to late instar *Aphidoletes* larvae. Results of toxicity studies conducted on third and fourth instar *Aphidoletes* larvae are presented in Table 9. Of the materials tested, Thiodan was found to be most toxic (46%) to late instar *Aphidoletes* larvae, while Systox was of moderate toxicity (32%). Phosphamidon, Imidan, and Guthion (Belchertown) were of low-moderate toxicity (16 to 18%) to late instar *Aphidoletes* larvae. The following materials were of low toxicity (6 to 12%) to late instar *Aphidoletes* larvae: Guthion (Fitchburg), Captan, Thiram, Zolone, Glyphosate, and Plictran.

DISCUSSION

Experimental Series A

Though A. aphidimyza was found to overwinter within a western Massachusetts apple orchard, adult eclosion did not occur until mid June. This agrees with the observed first appearance of Aphidoletes eggs on sampled foliage. The late appearance (June 28) of earliest detected Aphidoletes eggs on sampled foliage in 1974 (Fig. 1) most likely represents a failure to detect existing low numbers of eggs due to low sample numbers that year. Unfortunately, by early June, apple aphid populations have already reached injurious levels in some western Massachusetts orchards. Thus, owing to lack of biological synchrony between predator and prey, Aphidoletes is unable to prevent early season aphid damage. Once present, A. aphizimyza was responsible for considerable apple aphid mortality, dramatic aphid population reductions, and management of summer apple aphid populations. Therefore, for season-long management, apple aphid populations need to be maintained below injurious levels until the appearance of A. aphidimyza in mid June.

The economic threshold is the density level at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level. The economic injury level is the lowest population density that will cause economic damage, which is the amount of injury that will justify the costs of applied control measures. Hoyt and Burts (1974) state that economic thresholds for species which attack free fruit foliage are difficult to establish because of the many variables involved. As a result, economic threshold values for such species are infrequent and often contradictory.

Madsen and Bailey (1959) reported that a continuous apple aphid infestation is more damaging than a heavy infestation of short duration. Madsen et al. (1961) added that, for determining damage resulting from honeydew accumulations, the exact number of apple aphids per leaf is probably not as important as the distribution of aphids on a growing shoot. They reported heavy honeydew accumulations on fruit when apple aphid numbers rose above 5 aphids per seventh leaf from the terminal tip, and remained above this level for 8 weeks. Serious honeydew damage did not occur when apple aphids were limited only to terminal foliage (leaves 1 through 3 on the distal portion of an apple shoot). However, when infestations of 50 or more aphids per leaf occurred on the terminal foliage, aphids were also found on lower leaves of the shoot. The same authors add that if a leaf from the central portion of a growing shoot is aphid-infested, then the population is potentially damaging. Together, these results suggest to me that the economic threshold for the apple aphid is about 50 aphids per terminal leaf.

Oviposition studies (Table 1) showed that A. aphidimyza adults will readily oviposit in low density aphid colonies. These findings are consistent with those of the uncaged field population density studies. Overcrowding and reduced quality of the food source generally lead to a decrease in aphid reproduction and an increase in the production of alate forms, which leave the colony. Aphid exodus may also include walkers, as shown by the dispersal of apple aphids from the primary to secondary leaves on caged apple terminals (Table 4). Because it takes about 10 to 14 days for A. aphidimyza to complete development through the larval stage, eggs laid in high density aphid colonies might, therefore, be stranded in early larval stages without food. However, eggs laid in young rapidly expanding aphid colonies would have a more readily available food source throughout their larval development. Field population density studies showed that once *A. aphidimyza* was present in the orchard, its response to rising apple aphid numbers was always rapid (Figs. 1, 2, and 3), even during late summer when apple aphid numbers were very low. Chandler (1967) states that a predator that can oviposit in advance of an aphid infestation, or when the prey population is still at a very low density, is most likely to affect prey numbers and be more useful in biological control than one which is attracted only by relatively large numbers of prey.

In general, aphid consumption rate of *Aphidoletes* larvae varied with aphid abundance and was moderated by intraspecific larval competition (Tables 2 and 3). Thus, although the presence of a multiple number of *Aphidoletes* larvae on the same leaf reduced individual consumption rates, a high degree of apple aphid colony suppression generally resulted, owing to rapid and thorough predator coverage or influence over the food zone. LeCato (1976) reported that the anthocorid predator, *Xylocoris flavipes*, killed progressively more red flour beetles, *Tribolium castaneum* and black carpet beetles, *Attagenus megatoma*, as prey density increased, but fewer prey were killed per predator.

Why in each case was a single *Aphidoletes* larva acting alone less effective than a multiple number of larvae in suppressing apple aphids? Owing to low mobility in the early instars, a single *Aphidoletes* larva is apparently unable to exert a rapid predatory influence over an entire primary leaf surface. As a result, aphid reproductives are able to escape attack completely or for longer periods of time than would be possible at higher predator density levels. Thus, although a large number of apple aphids were killed by a single larva acting alone, many potential prey were not affected, leading to: (1) more aphid young being born to replace those killed, (2) more aphid young living to reproductive age, and (3) more aphids living to disperse to secondary leaves to start new apple aphid colonies. Among those starting prey-predator ratios least effective in aphid colony suppression, there was evidently an adequate supple of food (aphids) on the primary leaf to satisfy the Aphidoletes larva or larvae present. The net effect of this adequate food supply was a delay and/or a reduction in degree of larval predator dispersal to secondary leaves. As a result, apple aphid colonization occurred on secondary leaves, and was comparatively unaffected by the predator.

Results of the Aphidoletes oviposition sampling study in the orchard showed that experimental means of 133.6 apple aphids and 12.3 A. aphidimyza eggs were found per collected leaf. These means reduce to a field ratio of 10.9 apple aphids per cecidomyiid per leaf (approximately 11:1 ratio) which would fall within the reduced ratio range found to be most effective (up to and including the reduced ratio of 15:1) in apple aphid colony suppression during the 1976 density ratio caging studies. In the 1977 density ratio caging studies, the reduced ratio of 12:1 (starting ratio of 36:3) was the most effective one in apple aphid colony suppression, resulting in an 86%

reduction in aphid numbers. Thus, the orchard oviposition rate for Aphidoletes adults was found to be of approximately the same value as that predator to prey density ratio most effective in apple aphid colony suppression on caged apple terminals. This may explain how Aphidoletes was able to quickly reduce high density summer apple aphid populations in unsprayed control apple orchard blocks from 1974 through 1976 (Figs. 1, 2, and 3).

Madsen et al. (1975) were able to reduce the number of sprays needed to obtain apple aphid management in British Columbia by monitoring aphid populations. The need for treatment was established by sampling aphid populations, and sprays were recommended when 50% of the leaves sampled from 3 sections of apple shoots (third, seventh, and fifteenth leaves) were aphid infested. Adams (see Results section of Experimental Series B) was able to achieve successful apple aphid suppression in a western Massachusetts apple orchard even in blocks where the amount of spray material per treatment was reduced through use of an alternate row spray program. Aphid damage was not noticeable on reduced spray treated trees.

Moore (1974, 1976), in Connecticut, reported half spray treatments of Diazinon, Zolone, or Thiodan effective in reducing apple aphid populations, while allowing the survival of A. aphidimyza. Adams (see Results section of Experimental Series B) tested the toxicity of several orchard pesticides to A. aphidimyza in the laboratory, and reported Zolone, Imidan, and Thiodan to be of low or moderate toxicity to eggs and larvae. Such selective materials may be used in conjunction with A. aphidimyza to reduce and maintain apple aphid populations below suspected economic threshold levels of 5 aphids per leaf on central areas of apple shoots or 50 aphids per leaf on terminals. Such treatments may also have the effect of changing a pest to predator ratio from an ineffective one (in terms of prior control) to effective (Croft 1975).

Experimental Series B

The alternate row reduced spray program proved effective for apple aphid suppression in a western Massachusetts apple orchard. In 1974 and 1975 no significant differences in apple aphid numbers were found on foliage of reduced spray versus full spray treated tress. On 50% of the sampling dates in 1975 aphid numbers in the unsprayed control block were significantly higher than those in reduced or full spray treated blocks.

In 1974 and 1975 apple aphid populations in the unsprayed control block reached high densities (147.38 and 148.92 aphids per terminal) in late June to early July, and populations remained high for 5 and 2 weeks, respectively. In 1974, comparable apple aphid densities in the reduced spray treated block were not recorded until July 17, and remained high for only 3 weeks. In 1975, apple aphid numbers in the reduced spray treated block never reached high levels, as seen by the August 17 peak of 31.88 aphids per terminal. Adams (see Discussion section of Experimental Series A) suggested that the economic threshold for the apple aphid may be about 50 aphids per terminal leaf. However, this value would be expected to be lower on untreated trees due to greater opportunities for aphid distribution and longer persistence of high density aphid populations on untreated versus treated shoots.

This may explain why extensive aphid injury occurred in the unsprayed control block, but was not noticeable in reduced or full spray treated blocks. In addition to a greater persistence of apple aphid populations at high density levels, an earlier rise in apple aphid numbers to damaging levels in the unsprayed control block contribute to the differences in aphid damage between treatments. Some early season aphid damage in the unsprayed control block may also have been due to activities of the rosy apple aphid, Dysaphis plantaginea (Passerini).

Adams (see Results section of Experimental Series A) reported that adult eclosion of A. aphidimyza in a western Massachusetts apple orchard did not occur until mid June. Thus, Aphidoletes was not present early enough to check early season aphid damage in the unsprayed control block. However, it is significant to note that Aphidoletes was the only aphid predator found to occur in frequent numbers on sampled foliage in the pesticide treated blocks. This finding suggested that A. aphidimyza populations may be somewhat resistant or tolerant to certain orchard pesticides.

Laboratory toxicity studies showed that Guthion and Systox treatments have very detrimental effects on Belchertown populations of A. aphidimyza. However, Guthion was found to be only moderately toxic to Aphidoletes eggs collected from a commercial apple orchard at Marshall Farm in Fitchburg, MA. (Table 8). Thus, differential Guthion resistance appears to exist in Aphidoletes populations collected from 2 areas of the state. The Marshall Farm apple orchard in Fitchburg has received 7 to 8 Guthion treatments annually for 7 years at the dosage rate of ½ lb/100 gal. The section of the Belchertown apple orchard from which *Aphidoletes* eggs were collected for use in toxicity tests had not received insecticide or miticide treatments for 6 years. Only dormant oil and the fungicides Cyprex, Captan, and Thiram had been applied to the unsprayed control block during this period. Guthion resistance of *Aphidoletes* populations at Marshall Farm is not the first case of resistance of an arthropod natural enemy to Guthion; a number of predatory mites are known to have developed Guthion resistance (Croft and Brown 1975). Motoyama *et al.* (1971) reported that an organo-phosphate resistant strain of the predaceous mite, *Amblyseius fallacis* (Garman), degraded Guthion faster than a susceptible strain. Croft and Nelson (1972) reported that Guthion resistance in *A. fallacis* was widespread throughout the state of Michigan, and occurred wherever Guthion had been intensively applied for several years.

The fungicides Captan and Thiram, and the miticides Plictran and Omite were of low toxicity to all stages of *A. aphidimyza* tested. The herbicide Glyphosate, which is used for apple orchard weed control, was of low toxicity to late instar *Aphidoletes* larvae. Glyphosate has been found to be highly toxic to western Massachusetts populations of *A. fallacis* (Hislop, R., personal communication). Because last instar *Aphidoletes* larvae dropping to the ground to pupate could contact herbicide treatments, knowledge of the predator's response to Glyphosate treatments was highly desireable.

Zolone was the only insecticide tested that was of low toxicity to *Aphidoletes* eggs and larvae. These results agree with findings by Moore (1976), in Connecticut, that half sprays of Zolone allowed survival of *Aphidoletes* larvae on Zolone treated trees. Unfortunately, Zolone has been found to be very toxic to A. fallacis (Hislop, R., personal communication), the most important mite predator in western Massachusetts apple orchards. Phosphamidon treatments were moderately toxic to Aphidoletes eggs and first instar larvae hatching from treated eggs, thus resulting in a high (52%) total mortality value. Thiodan and Imidan were only moderately toxic to predaceous cecidomyiids, and have been found to be of low toxicity to A. fallacis (Hislop, R., personal communication). Moore (1974) reported that half sprays of Thiodan were effective in reducing apple aphid numbers, while allowing A. aphidimyza populations to increase. Therefore, of the materials tested, Imidan should be the broad-spectrum insecticide of choice and Thiodan the aphicide of choice for good pest insect-aphid control, while allowing at least moderate survival and build-up of aphid and mite predators in western Massachusetts apple orchards. Further development of Guthion resistance in Aphidoletes populations in commercial apple orchards could enhance the role of Guthion as a selective insecticide allowing aphid and mite predator survival.

Those materials used in reduced and full spray treatment blocks in 1974 and 1975 after the appearance of A. aphidimyza in mid June included: Thiram, Captan, Omite, Imidan, and Thiodan. Each of these materials was found to be of low or moderate toxicity to A. aphidimyza, thus allowing the survival of predaceous cecidomyiids observed in such treatment blocks.

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APPENDIX

Fig. 1.-Population densities of the apple aphid, _Aphis pomi_, and the predaceous cecidomyiid, _Aphidoletes aphidimyza_. Belchertown, MA. 1974.

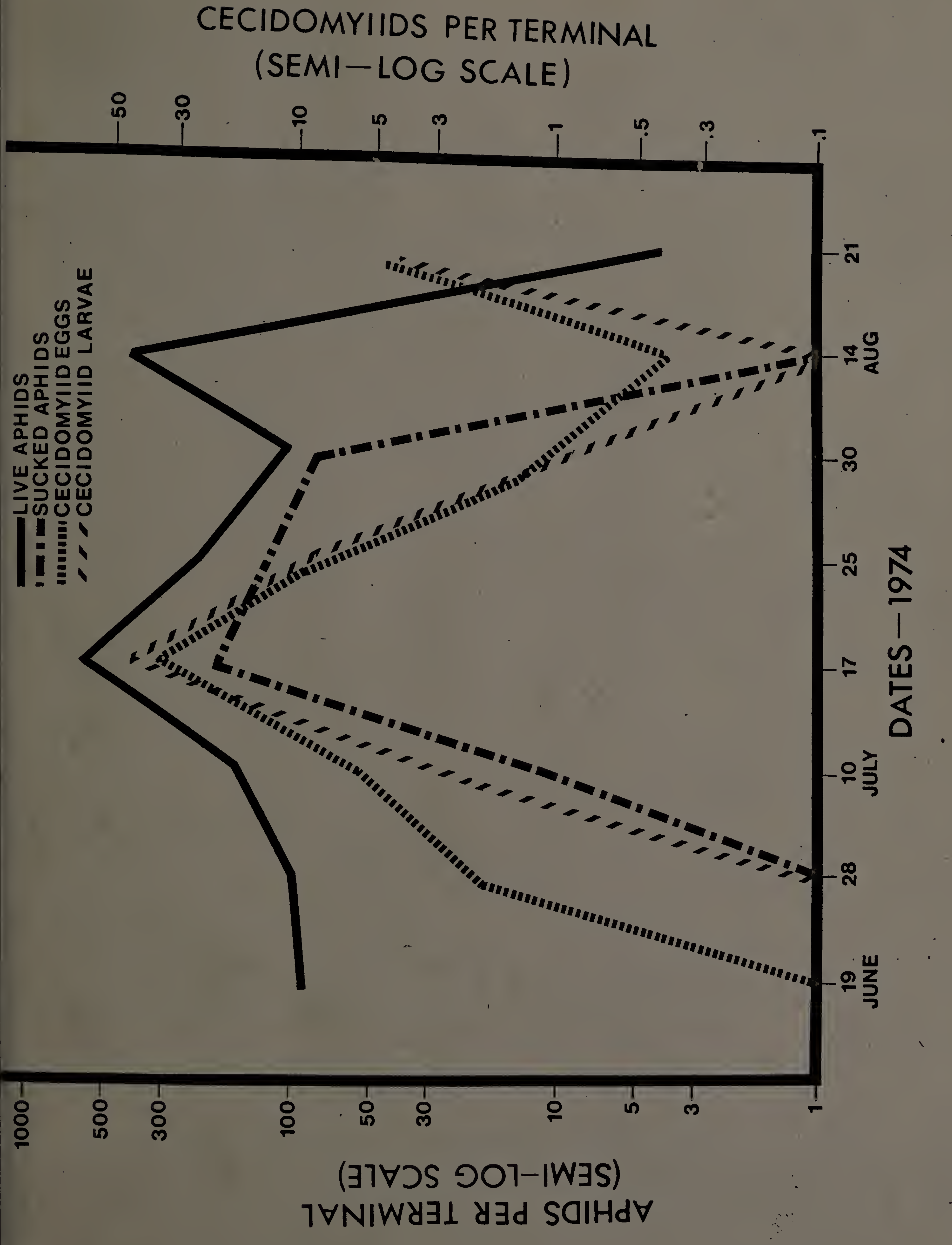

CECIDOMYIIDS PER TERMINAL
(SEMI—LOG SCALE)
50
30
10
5
3
1
.5
.3
.1
LIVE APHIDS
SUCKED APHIDS
CECIDOMYIID EGGS
CECIDOMYIID LARVAE
19
JUNE
28
10
JULY
17
25
30
14
AUG
21
DATES—1974
1000
500
300
100
50
30
10
5
3
1
APHIDS PER TERMINAL
(SEMI—LOG SCALE)

Fig. 2.-Population densities of the apple aphid, *Aphis pomi*, and the predaceous cecidomyiid, *Aphidoletes aphidimyza*. Belchertown, MA. 1975.

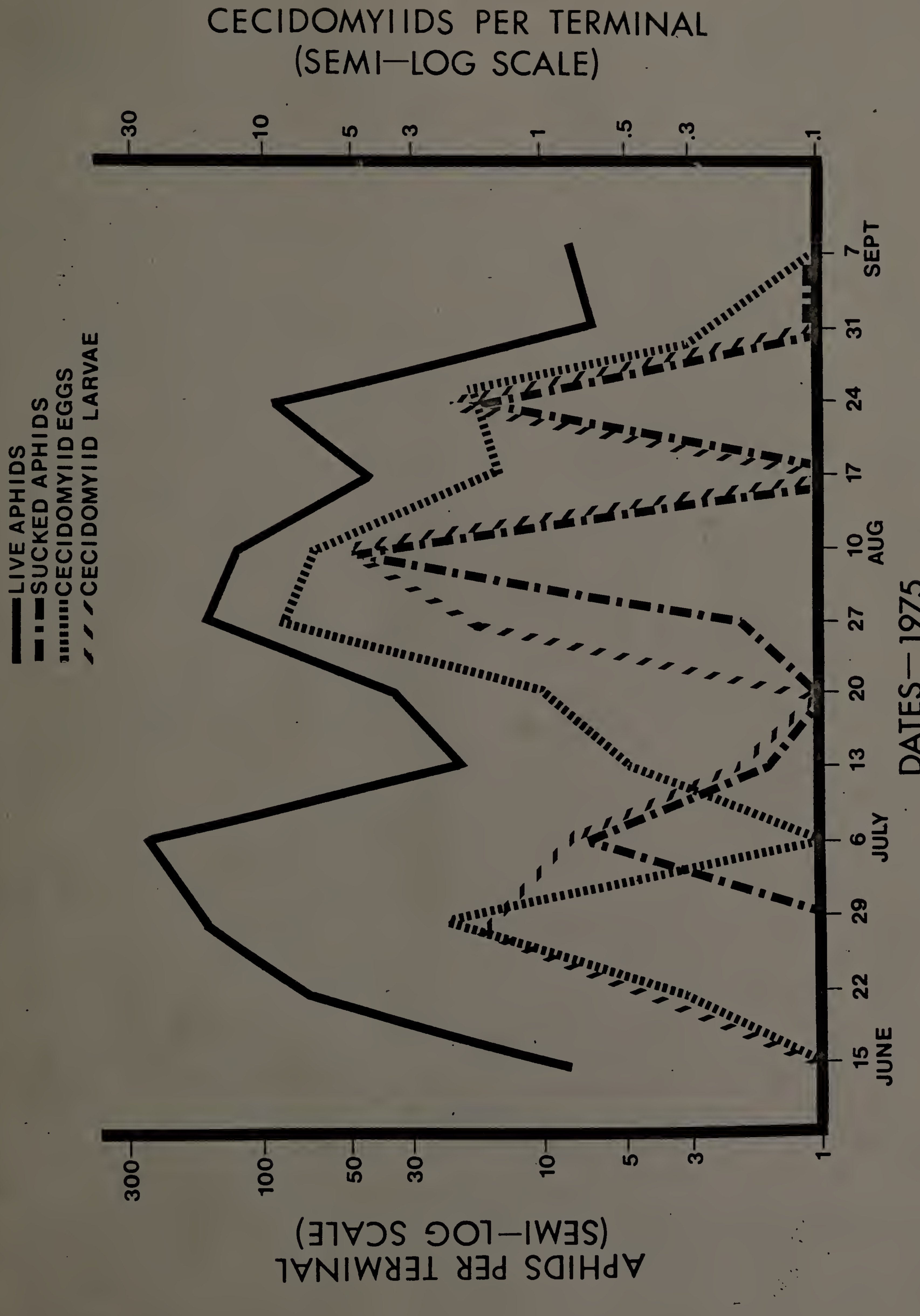
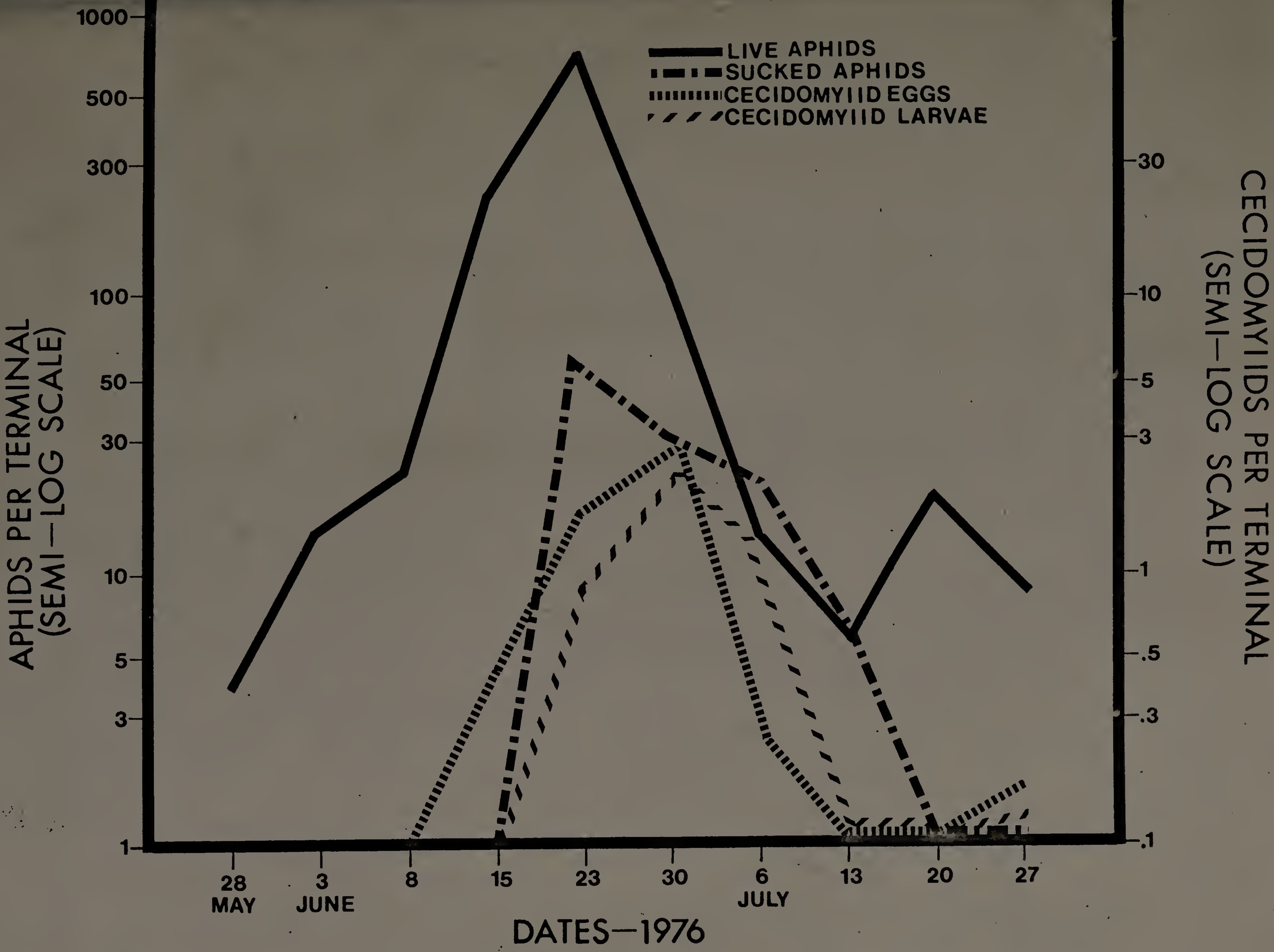

CECIDOMYIIDS PER TERMINAL
(SEMI–LOG SCALE)
30
10
5
3
1
.5
.3
.1
LIVE APHIDS
SUCKED APHIDS
CECIDOMYIID EGGS
CECIDOMYIID LARVAE
15 JUNE
22
29
6 JULY
13
20
27
10 AUG
17
24
31
7 SEPT
DATES—1975
300
100
50
30
10
5
3
1
APHIDS PER TERMINAL
(SEMI–LOG SCALE)

Fig. 3.-Population densities of the apple aphid, Aphis pomi, and the predaceous cecidomyiid, Aphidoletes aphidimyza. Belchertown, MA. 1976.



LIVE APHIDS
SUCKED APHIDS
CECIDOMYIID EGGS
CECIDOMYIID LARVAE
APHIDS PER TERMINAL (SEMI—LOG SCALE)
1000
500
300
100
50
30
10
5
3
1
CECIDOMYIIDS PER TERMINAL (SEMI—LOG SCALE)
30
10
5
3
1
.5
.3
.1
28 MAY
3 JUNE
8
15
23
30
6 JULY
13
20
27
DATES—1976

Table 1.–Oviposition of Aphidoletes aphidimyza in an unsprayed section of a western Massachusetts apple orchard.

No. aphids/ leaf[1]	No. leaves with cecidomyiid eggs[2]	Mean no. eggs/ leaf
1 - 100	47	10.2
101 - 200	25	8.0
201 - 300	14	16.8
301 - 400	7	11.3
401 - 500	2	88.0

[1]Aphidoletes eggs are seldom found on apple leaves with no apple aphids present. In 3 years of sampling, there were 2 leaves found where Aphidoletes eggs were present in the absence of apple aphids.

[2]Based on 95 leaves which harbored only apple aphids and eggs of Aphidoletes aphidimyza.

Table 2.-Effect of various prey-predator density ratios on colony suppression of the apple aphid, *Aphis pomi*, and aphid consumption rates for larvae of *Aphidoletes aphidimyza*. Belchertown, MA. 1976.

		Mean no.	
Starting ratio[1]	Reduced ratio	Aphids killed/ cecidomyiid	Aphids living at end of experiment[2]
20:8	2.5:1	4.2[3]	0.6
60:16	3.8:1	6.0	0.3
20:4	5:1	8.4	0.0
180:16	11.5:1	10.7	0.3
60:4	15:1	19.9	0.7
20:1	20:1	32.3	10.7
180:4	45:1	58.4	53.5
60:1	60:1	45.7	55.0
180:1	180:1	65.1	120.7
20:0	20:0	——	84.7
60:0	60:0	——	124.7
180:0	180:0	——	120.7

[1]Apple aphids : *Aphidoletes aphidimyza* eggs.
[2]Experimental period covered 12 days.
[3]Means based on 3 replicates.

Table 3.-Effect of various prey-predator density ratios on colony suppression of the apple aphid, *Aphis pomi*, and aphid consumption rates for larvae of *Aphidoletes aphidimyza*. Belchertown, MA. 1977.

		Mean no.		
Starting ratio[1]	Reduced ratio	Aphids killed/ cecidomyiid	Aphids living at end of experiment[2]	% change in no. aphids[3]
12:1	12:1	18.3[4]	8.8	- 27
36:3	12:1	13.3	5.0	- 86
15:1	15:1	20.0	8.3	- 45
45:3	15:1	15.5	18.5	- 59
18:1	18:1	24.8	28.0	+ 56
54:3	18:1	17.5	26.8	- 50
12:0	12:0	——	94.0	+ 683
15:0	15:0	——	193.0	+ 1186
18:0	18:0	——	213.0	+ 1083
36:0	36:0	——	337.0	+ 836
45:0	45:0	——	297.0	+ 560
54:0	54:0	——	314.0	+ 481

[1]Apple aphids : *Aphidoletes aphidimyza* eggs.

[2]Experimental period covered 10 days.

[3]See the Results section of Experimental Series A under the subdivision "Density ratios of *Aphis pomi* to *Aphidoletes aphidimyza* - 1977" for the formula used to calculate % change in number of aphids.

[4]Means based on 4 replicates.

Table 4.—Dispersal of the apple aphid and the predator, Aphidoletes aphidimyza on a caged apple terminal. Belchertown, MA. 1976. APL = number of living aphids on the primary leaf, SAPL = number of sucked aphids on the primary leaf, ASL = number of living aphids on secondary leaves, SASL = number of sucked aphids on secondary leaves, CPL = number of cecidomyiids on the primary leaf, and CSL = number of cecidomyiids on secondary leaves.

Date	APL	SAPL	ASL	SASL	CPL	CSL
July 31	60	0	0	0	16	0
August 2	73	2	5	0	16	0
August 4	25	23	30	0	16	0
August 6	0	14	0	42	1	15
August 11	0	0	0	0	0	0

Table 5.-Schedule and rates of pesticide applications used in reduced spray and full spray treated blocks of apple. Belchertown, MA. 1974.

Application	Date	Material	Total lbs material/ tank	Concentration	Gal water
Green tip	4/18	Cyprex 65 WP	2¼	6X	100
Quarter inch green	4/22	Repeat above			
Half inch green	4/25	Cyprex 65 WP Guthion 50 WP Superior oil	2 2 3/4 8	1X	550 400
Tight cluster	4/29	Cyprex 65 WP	2¼	6X	100
Pre-pink	5/3	Cyprex 65 WP Guthion 50 WP	2¼ 3	6X	100
Pink	5/9	Thiram 50 WP Guthion 50 WP Systox 6 EC	12 2 3/4 2½	6X	100
Full pink	5/14	Thiram 50 WP	12	6X	100
Petal fall	5/21	Thiram 50 WP Guthion 50 WP	9 3	6X	100
1st cover	5/27	Cyprex 65 WP Imidan 50 WP	2¼ 9	6X	100
2ond cover	6/3	Thiram 50 WP Guthion 50 WP	9 3 3/4	6X	100
3rd cover	6/18	Captan 50 WP Imidan 50 WP	9 9	6X	100
4th cover	6/28	Repeat above			
5th cover	7/8	Captan 80 WP Imidan 50 WP	3 3/4 6	6X	100
6th cover	7/22	Captan 80 WP Imidan 50 WP Omite 30 WP	3 3/4 6 9	6X	100
7th cover	8/5	Captan 80 WP Imidan 50 WP	3 3/4 6	6X	100

Table 6.-Schedule and rates of pesticide applications used in reduced spray and full spray treated blocks of apple. Belchertown, MA. 1975.

Application	Date	Material	Total lbs material/ tank	Concen-tration	Gal water
Green tip	4/24	Cyprex 65 WP	3½	6X	150
Half inch green	5/1	Cyprex 65 WP Superior oil	2¼ 18	1X	900
Three-quarter inch green	5/5	Cyprex 65 WP	3½	6X	150
Tight cluster	5/9	Cyprex 65 WP Guthion 50 WP	3½ 4½	6X	150
Early pink	5/12	Cyprex 65 WP	3½	6X	150
Pink	5/15	Cyprex 65 WP Guthion 50 WP	3½ 4½	6X	150
Petal fall	5/23	Thiram 50 WP Guthion 50 WP	13½ 5 5/8	6X	150
1st cover	5/29	Repeat above			
2ond cover	6/12	Thiram 50 WP Imidan 50 WP	13½ 13½	6X	150
3rd cover	6/20	Captan 50 WP Imidan 50 WP Thiodan 50 WP	9 9 9	6X	150
4th cover	7/7	Captan 50 WP Imidan 50 WP Thiodan 50 WP Omite 30 WP	9 9 9 9	6X	150
5th cover	7/18	Captan 50 WP Imidan 50 WP Omite 30 WP	9 9 9	6X	150
6th cover	7/31	Captan 80 WP Imidan 50 WP	5 5/8 9	6X	150
7th cover	8/16	Repeat above			

Table 7.—Presence of the apple aphid, *Aphis pomi*, and the predator, *Aphidoletes aphidimyza*, in orchard blocks which received full spray (2 sides of tree) and reduced spray (1 side of tree) coverage treatments. Belchertown, MA. 1974 and 1975.

	Mean no. insects/terminal[1,2]					
	Aphis pomi			*Aphidoletes aphidimyza*[4]		
Date	Full	Reduced	Control[3]	Full	Reduced	Control
			1974			
June 19	0.00a	0.00a	83.13a	0.00a	0.00a	0.00a
June 28	0.63a	3.75a	88.00a	0.00a	0.00a	1.88a
July 10	0.13a	0.25a	147.38a	0.00a	0.00a	7.75b
July 17	10.13a	71.38a	518.75a	0.00a	0.88a	70.38b
July 25	15.63a	150.13a	206.50a	0.13a	4.50c	16.88b
July 30	9.38a	238.00a	100.38a	0.00a	7.63b	2.25a
Aug. 14	140.63a	478.88a	384.75a	4.13b	5.13b	0.38a
Aug. 21	11.88a	0.38a	3.75a	8.88b	3.25a	9.50b
			1975			
June 15	0.88a	0.67a	8.08a	0.00a	0.00a	0.00a
June 22	7.71a	6.21a	76.04b	0.00a	0.00a	0.30a
June 29	0.33a	0.21a	148.92b	0.00a	0.00a	3.83b
July 6	2.50a	6.00a	212.83b	0.00a	0.00a	0.83b
July 13	0.38a	1.13a	19.25a	0.00a	0.00a	0.71b
July 20	3.33a	2.42a	31.38a	0.46c	0.00a	1.00b
July 27	6.71a	10.46a	143.21b	0.04a	0.00a	10.63b
Aug. 10	2.63a	13.67a	109.83b	0.50a	1.54c	10.25b
Aug. 17	6.04a	31.88a	38.71a	0.13a	0.21a	1.58b
Aug. 24	9.46a	20.13a	78.46b	0.00a	0.00a	3.67b
Aug. 31	13.21a	17.46a	6.50a	0.00a	0.00a	0.25a
Sept. 7	9.38a	10.38a	7.75a	0.00a	0.46b	0.04a

[1]In 1974 and 1975, 3 distal leaves of 1 terminal from 8 and 24 trees/treatment/date, respectively, were sampled.

[2]Means on individual sample dates followed by the same letter are not significantly different at the 5% level of Duncan's multiple range test.

[3]No insecticides or miticides applied.

[4]Eggs and larvae combined.

Table 8.-Laboratory toxicity[1] of orchard pesticides to <u>Aphidoletes</u> <u>aphidimyza</u> eggs and early[2] larvae hatching from treated eggs.

Treatment[3]	Dosage/100 gal spray	% egg mortality	% early larval mortality	% total mortality[4]
Imidan 50 WP	1½ lbs	8	24	30
Guthion 50 WP	5/8 lb	86	14	88
Guthion 50 WP (Fitchburg)	5/8 lb	6	38	42
Thiodan 50 WP	1 lb	6	29	34
Systox 6 EC	5 ozs	8	57	60
Zolone 3 EC	1½ pts	4	0	4
Sevin 50 WP	1 lb	72	21	78
Phosphamidon 8 EC	¼ pt	34	27	52
Plictran 50 WP	5 ozs	14	0	14
Omite 30 WP	1½ lbs	6	2	8
Thiram 50 WP	2 lbs	6	0	6
Captan 50 WP	1 lb	8	2	10
Check	——	4	6	10
Check (Fitchburg)	——	5	0	5

[1]All mortalities were determined 72 hours after eggs were treated.

[2]First instar larvae.

[3]<u>Aphidoletes</u> eggs of those Guthion and Check treatments followed by "(Fitchburg)" were collected from a commercial apple orchard at Marshall Farm in Fitchburg, MA. Eggsfor all other treatments were collected from an unsprayed section of an apple orchard at the Fruit Research Center in Belchertown, MA.

[4]See the Materials and Methods, Experimental Series B section on "Toxicity of orchard pesticides to <u>Aphidoletes</u>" for the formula used to calculate % total mortality.

Table 9.-Laboratory toxicity of orchard pesticides to late[1] instar larvae of Aphidoletes aphidimyza.

Treatment[2]	Dosage/100 gal spray	% late larval mortality[3]
Imidan 50 WP	1½ lbs	18
Guthion 50 WP	5/8 lb	18
Guthion 50 WP (Fitchburg)	5/8 lb	6
Zolone 3 EC	1½ pts	10
Thiodan 50 WP	1 lb	46
Systox 6 EC	5 ozs	32
Phosphamidon 8 EC	¼ pt	16
Plictran 50 WP	5 ozs	12
Glyphosate 4 EC	4 qts	10
Captan 50 WP	1 lb	6
Thiram 50 WP	2 lbs	8
Check	——	8
Check (Fitchburg)	——	3

[1]Third and fourth instar larvae.

[2]Aphidoletes larvae of the Guthion and Check treatments followed by "(Fitchburg)" were collected from a commercial apple orchard at Marshall Farm in Fitchburg, MA. Larvae for all other treatments were collected from an unsprayed section of an apple orchard at the Fruit Research Center in Belchertown, MA.

[3]Mortality was determined 96 hours after treatments.